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NASA Lewis Wind Tunnel Model Systems Criteria

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1.0 SUMMARY

This report describes criteria for the design, analysis, quality assurance, and documentation of models or test articles that are to be tested in the aeropropulsion facilities at the NASA Lewis Research Center. The report presents three methods for computing model allowable stresses on the basis of the yield stress or ultimate stress, and it gives quality assurance criteria for models tested in Lewis' aeropropulsion facilities. Both customer-furnished model systems and in-house model systems are discussed.

The functions of the facility manager, project engineer, operations engineer, research engineer, and facility electrical engineer are defined. The format for pretest meetings, prerun safety meetings, and the model criteria review are outlined. Then, the format for the model systems report (a requirement for each model that is to be tested at NASA Lewis) is described, the engineers that are responsible for developing the model systems report are listed, and the time table for its delivery to the facility manager is given.

2.0 INTRODUCTION

This report defines the criteria for the design, analysis, quality control assurance, and documentation of wind tunnel models that are to be tested in the following aeropropulsion facilities at the NASA Lewis Research Center: the 1- by 1-Foot Supersonic Wind Tunnel, the 10- by 10-Foot Supersonic Wind Tunnel, the 8- by 6-Foot Supersonic Wind Tunnel, the 9- by 15-Foot Low-Speed Wind Tunnel, and the Icing Research Tunnel. These facilities are managed and operated by Lewis' Aeropropulsion Facilities and Experiments Division (AFED). Customers should contact the facility managers (app. A) to schedule tests and use these facilities.

This report is designed to be used in conjunction with the specific tunnel information presented in the wind tunnel manuals (refs. 1 to 4).

3.0 BACKGROUND INFORMATION

3.1 Terminology

AFED electrical engineer The AFED electrical engineer is responsible for reviewing and installing all model electrical, electronic, and data equipment and connections needed for particular tests. This engineer also reviews and installs all model and facility instrumentation that are required by the research engineer and the AFED project engineer.

AFED operations engineer The AFED operations engineer supports the preparation, installation, and testing of the model and auxiliary systems. Usually, a mechanical and an electrical engineer are assigned as operations engineers to a test program. The AFED mechanical operations engineer conducts the tunnel test and plans each tunnel run. This engineer is in charge in the tunnel control room during the run and directs the model and facility operators to accomplish the run objectives.

AFED project engineer The AFED project engineer is responsible for project planning, project management of the test program, making any required facility modifications, reviewing all model and support system drawings and stress analysis, and properly installing the model and ancillary equipment into the facility test section. The AFED project engineer can also serve as the AFED operations engineer and the research engineer. In addition, the AFED project engineer assists the facility manager in interpreting the requirements of this report.

The AFED project engineer has the overall responsibility for the safe operation of the test but may seek the assistance of engineers in Lewis' Engineering Directorate to verify model integrity. The AFED project engineer also is responsible for developing the project instrumentation manual, which contains both the model and facility instrumentation requirements. The research engineer (see definition in this section) supplies the AFED project engineer with the model research instrumentation requirements for this manual.

Critically loaded/stressed component This is a component that is critical to the structural integrity of the model and whose failure can result in model system loss or facility damage.

Critical speed This is the speed of the rotating system that corresponds to a resonant frequency of the model system.

Facility manager The facility manager schedules and supervises the operation of the facility. The facility manager presents the program to the AFED Chief, who represents the final approval authority for all models that are to be tested in Lewis' aeropropulsion facilities. The procedure for contacting the facility managers is outlined in appendix A, and the procedure for scheduling a facility is outlined in appendix B.

Facility-user-furnished model system When the facility user (i.e., research engineer) is not from NASA Lewis, this user must provide adequate documentation regarding the structural integrity of the model and ancillary systems under the required loads to the assigned Lewis research engineer and the AFED project engineer (see definition in this section) for review.

In-house-furnished model system This is a model system that is designed and fabricated with Lewis review and manufacturing control.

Model design engineer The model design engineer develops the models per the request of the research engineer and with assistance from the AFED project engineer. This engineer also prepares the engineering drawings for model fabrication and installation and supervises model fabrication. The model design engineer keeps the research engineer and the AFED project engineer informed about progress toward model completion (usually on a monthly basis) and consults with them as required.

Model systems The model systems covered in this report include, but are not limited to, aircraft or parts of aircraft models, turbine engines, turbomachinery components (e.g., fans or compressor rigs), flow survey rakes and arrays, splitter plates, and model support hardware (including force balances, struts, and stings). In this report, "model systems" does not apply to

- (1) Model support equipment that is a permanent part of the facility
- (2) Items—such as gear boxes, motors, actuators, and instrumentation mounts—that are not critical to the structural integrity of the model system and whose failure cannot damage the facility
- (3) Auxiliary equipment, such as tunnel cables and foundations

Prerun safety meeting The AFED project engineer prepares a Safety Permit Request that describes the test. This document discusses the safety aspects of the test as well as test objectives, run schedule, instrumentation, hardware, and other factors. It is sent through the facility manager to the Lewis' Environmental Compliance Office and to the appropriate Area Safety Committee for their review and approval. The Safety Permit should be available for review by the Area Safety Committee at least 2 months before the scheduled test.

Pretest meetings A series of pretest meetings are held to discuss the test plan, instrumentation, facility hardware, and data requirements. The first pretest meeting should be set up as far in advance as is practical (at least 1 year before the tunnel test). The attendees at this meeting are usually the facility user, the facility manager, and the AFED project engineer. Ensuing pretest meetings are scheduled by the AFED project engineer. These meetings are attended by the facility users (e.g., the lead research engineer and key research personnel), the facility manager, appropriate AFED branch chiefs, key AFED personnel, the AFED project engineer, and Research Analysis Center programmer analysts (if required). The number of pretest meetings is usually a function of test complexity.

Research engineer The research engineer may be from NASA Lewis, another NASA center, another U.S. Government agency, or a private corporation. The research engineer (i.e., the customer) oversees the model configuration definition. When the lead research engineer is from NASA Lewis, the responsibilities of model design and fabrication are shared with the AFED project engineer. The research engineer also defines the test matrix and instrumentation requirements for the test program and the engineering parameters and equations sets that are part of the computing requirements package. This package must be delivered to application programmers in the Research Analysis Center for implementation on Lewis computing systems (both centralized systems and those dedicated to specific facilities) at least two months prior to the start of the test.

When the lead research engineer is from another NASA center, another U.S. Government agency, or a private corporation, a Lewis research engineer is also assigned to the project and serves as a point of contact between the customer and in-house activities at NASA Lewis. The Lewis research engineer obtains the required test matrix, model stress, and load calculations from the customer (see definition of Facility-user-furnished model system in this section) and meets with the AFED project engineer (see definition in this section) to discuss the project instrumentation manual. If the assistance of Research Analysis Center programmers is required for data reduction, the Lewis research engineer also obtains a computer requirements package from the customer at least two months prior to the start of the test.

3.2 Model Criteria Implementation

The facility manager has the responsibility and the authority to implement the criteria in this report. The facility manager may elect to seek assistance from the AFED project engineer and the research engineer. The research engineer and the AFED project engineer share the responsibility of ensuring that the model and system design and fabrication meet the criteria of this report. Any deviations in these criteria must be addressed according to the deviation procedure outlined in section 8.0.

3.3 Model Reviews

Model system reviews take place through pretest meetings (see definition, sec. 3.1) at regularly scheduled intervals during the model buildup and installation phase of the program. The schedule and attendees for these meetings are determined by the AFED project engineer. In addition to these regular meetings, during the model

buildup and testing phase, it may be necessary to have engineering review meetings to discuss problems with the model. These meetings are not scheduled on a regular basis but as required during the program. The AFED project engineer schedules these meetings and contacts the attendees.

4.0 DESIGN AND ANALYSIS

4.1 Design Loads

At least 4 months prior to the start of testing at Lewis, the model design engineer must supply model design loads to the research engineer. These loads must be consistent with the safe limits of the AFED facilities (refs. 1 to 4), and they must be included in the model systems report (see sec. 6.1). The research engineer and the AFED project engineer must agree with the conclusions of the model design engineer.

4.2 Material Selection

4.2.1 Standards.—The materials used for the model and the support structure must be selected according to their mechanical properties from experimental test data or from the latest publications of the following organizations, codes, regulations, and handbooks:

- (1) American Institute for Steel Construction (AISC)
- (2) American National Standards Institute (ANSI)
- (3) American Society of Mechanical Engineers (ASME)
- (4) American Society for Testing and Materials (ASTM)
- (5) American Welding Society (AWS)
- (6) American Society for Nondestructive Testing (ASNT)
- (7) National Institute of Standards and Technology (NIST)
- (8) National Design Specifications for Stress Grade Lumber (NDSSGL)
- (9) Society of Automotive Engineers (SAE)
- (10) ASME Boiler and Pressure Vessel Code
- (11) National Electric Code (NEC) (applicable to wiring that is external to the model)
- (12) Department of Transportation Regulations (DOT)
- (13) Federal Aviation Regulations (FAR)
- (14) Aerospace Structural Metals Handbook—Department of Defense (DOD)
- (15) Military Handbook #5—Department of Defense (DOD)

4.2.2 Adjustments for environment.—All material properties, design criteria, and allowable stresses must be suitably adjusted for test temperature, pressure, and any other environmental effects that may be present when the material is under stress.

4.2.3 Material properties verification.—Materials that are used for critically stressed components and/or are subject to nonstandard or special processing must have as-built properties (i.e., properties that take into account changes in the model or system material properties due to the fabrication processes) verified at test temperature. The material verification techniques (e.g., tensile testing techniques) should be developed by the AFED project engineer and the research engineer after consultation with members of Lewis' Structural Systems Division.

4.2.4 Galling.—Galling and galvanic corrosion must be considered in selecting materials for all model and auxiliary systems. Tunnel operation resulting in high-frequency vibrations (i.e., the vibrations that accompany a tunnel unstart condition) would aggravate galling. Galling has occurred with close-fitting parts, especially

threaded items with large, fine-threaded diameters ($\frac{1}{2}$ -in. diameter or larger). Fine grit that may be circulated in a tunnel should be removed from the test section to prevent problems with close-fitting parts on the model or auxiliary support systems.

4.2.5 Nonmetallic materials.—Nonmetallic materials that are used to manufacture models or model support systems require special considerations. Fine grit circulating in the wind tunnels can also damage the nonmetallic materials used in model or model support systems, therefore test section cleanliness is paramount. Wood materials selected for a model or model support systems should be resistant to warping, easy to work, glue well, and take all types of finishes. At low dew points, tunnel operation could dry and crack any woods used in the models or model support systems.

Plastics, epoxy resins, and fiberglass materials may soften with elevated temperatures in the test section and experience loss in strength or other mechanical properties. These topics, if applicable, should be discussed at the first pretest meeting held at NASA Lewis.

4.3 Structural Analysis

4.3.1 Stress analysis.—A stress analysis is required as part of the model systems report (sec. 6.1).

(1) The stress analysis should show that allowable stresses are not exceeded for the worst case loads.

(2) For each model section that is analyzed, the model design engineer should prepare a sketch showing the forces and moments on that section. These sketches should list the approximations, assumptions, model section properties, and material allowables.

(3) All general equations and their sources must be listed before numerical values are substituted into the equations.

(4) Model stations should be established along the longitudinal axis of the model, and the cross-sectional area of the model should vary by at least 5 percent from one section to the next. Each section should be analyzed to determine the allowable shear, axial load, bending, and torsion of structural members to locate the critical sections of the model.

(5) The model systems report should show that the model, the mounting points (including struts and stings), and the restraints are statically and dynamically stable within the model operating envelope. The effects of Reynolds number, Mach number, surface conditions, and other factors in the development of the equations noted in the analysis should be discussed. The range of mass and inertia parameters plus the stiffness coefficients used in the analysis also should be noted.

(6) Some models that are tested in the tunnels (specifically, in the Icing Research Tunnel and the 9- by 15-Foot Low-Speed Wind Tunnel) are flight-type hardware, and the allowable stresses are adjusted to reflect this fact. AFED suggests that the aerodynamic category of the model be determined (i.e., normal, transport, rotorcraft, utility, or commuter) and that the Federal Aviation Regulations for the model category be consulted to determine the allowable stresses (i.e., factor of safety, strength, and deformation). The specific Federal Aviation Regulations manual that is used to determine the allowable stresses on the model should be noted in the model systems report.

(7) If used, finite element analyses documentation must include computer-generated plots of the finite element model or models, a tabular or graphical summary of stress data, and the name of the structural code used. Finite element models must be validated by either closed-form solution approximations or by other evidence that shows a high confidence level in the finite element model—such as equilibrium checks and convergence accuracy of solution.

(8) When model loading is being established (steady-state and startup), an additional 10° flow angle should be added to the maximum model angle of attack with respect to the free stream to establish the model design loads. This should be done in both the pitch and yaw directions. The dynamic pressure used should be the

maximum tunnel dynamic pressure as given by the facility operating envelope or as stated in references 1 to 4. With this criterion, the allowable stresses should not exceed one-half of the yield stress. All auxiliary parts of the model exposed to the airstream and nominally at 0° angle of attack should be evaluated at 10° angle of attack for steady-state and startup loads. This technique for considering steady-state and startup loads applies to both subsonic and supersonic conditions. Models unusual in size, shape, or operation may require special analysis. Loads for such models can be discussed with the AFED project engineer.

4.3.2 Thermal analysis.—The model must be analyzed to examine thermal stresses and distortions for both steady-state and transient conditions.

4.3.3 Fatigue analysis.—To the extent that fatigue is a credible failure mode, model components that are subjected to cyclic loadings must be analyzed for fatigue. The fatigue analysis is performed on the premise that no flaws or cracks exist in the structure.

4.3.4 Design life.—The model design engineer specifies the design life requirements for the fatigue analysis of model system components. If the projected load-cycle/design life requirement is not well defined, the following approximation may be used:

Estimate the number of times a model system component will experience maximum steady-state load conditions (i.e., peak load cycles) over the test life, and multiply this number by three. This number can be used as the primary design life-cycle requirement.

4.4 Mechanical Connections

4.4.1 Structural joints.—All counterbores, spotfaces, and countersinks in the model and other support structures must be properly aligned so that torquing does not deform the fasteners.

The minimum safety factor for bolted joints that clamp the model, sting, model auxiliary structure, or model equipment is 4.0 on the basis of yield stress and 5.0 on the basis of ultimate stress for heat-treated hardened bolts. The safety factors are based on bolt cross-sectional area, not on the tightened or proof load (i.e., the maximum load that can be applied to a bolt without obtaining a permanent set or a permanent stretch).

The cross-sectional area of the bolts is determined by first calculating the load on the model or model support system mating parts flange or joint for (1) a predetermined hydrostatic, or most severe, test condition and (2) at a room-temperature bolting-up condition. The flange or joint load is then divided by the allowable stresses obtained from bolt material tables at the temperature condition determined from steps 1 or 2 above. Note that the allowable stress sometimes has an appropriate safety factor figured into its table value (this depends on the reference that is used). The division of the flange or joint load by the allowable stress defines the total cross-sectional area for the bolts. This calculation does not define the tightness or tension required on the bolts. Current engineering practice requires tightening bolts from 75 to 90 percent of proof load. The individual bolts will have a safety factor of 1.25 to 1.50 (if based on ultimate stress divided by the proof stress of the material), but the flange or joint will have a much higher safety factor if it is based on the required area. The loads on bolts used to fasten a flat-faced joint are discussed in appendix C. Shear loads should be transmitted through the use of keys, pins, and shoulders; and the keys and pins should be properly retained.

All welded joints should be designed in accordance with the American Welding Society (AWS) structural codes (AWS D1.1, steel; AWS D1.2, aluminum; and AWS D1.3, sheet steel). All critical joints whose failure could damage the model, model components, or facility must be radiographed to the requirements of the applicable AWS code. Alternative nondestructive testing methods may be used, but these must meet the AWS

codes as specified by the AFED project engineer. Weld disposition for nondestructive testing must be as specified in section 6 of the AWS codes.

4.4.2 Fasteners.—All structural bolted or screwed connections must be provided with positive mechanical locks, such as locking inserts, self-locking nuts, and safety wiring. Fastener thread engagement must be 1.33 times as strong as the bolt preload.

4.5 Metallic Materials Allowable Stress

The allowable stress criteria for metallic materials given in this section are based on well-established design practices. Three methods are discussed for establishing stress design allowables. Methods 1 and 1A are based on conservative approaches that can be used where structural design optimization is not a factor and minimum analysis is needed. Method 2 is a systematic approach that can yield a more optimum structural design. It is acceptable to design some parts of a model system according to the requirements of methods 1 or 1A and other parts of the model system according to the requirements of method 2.

4.5.1 Stress computations using method 1.—The allowable stress for maximum loading is the smaller of one-fifth of the minimum ultimate stress or one-third of the minimum yield stress of the material. This corresponds to a safety factor of 5 on ultimate stress and of 3 on yield stress. The maximum shear theory of failure (elastic failure is defined to occur when the maximum shear stress equals one-half of the yield stress) is used when allowable levels for combined stresses are calculated. In cases where the shear stress of the material is not known, the maximum allowable shear stress is taken as one-sixth of the tensile yield stress of the material. Thermal stresses that may occur on the model should be added to the load stresses before determining the factor of safety. The allowable stresses are the value at the operating temperature. The material properties that are used in the calculations should be the expected minimum values.

4.5.2 Stress computations using method 1A.—In some cases, the model design engineer may wish to use this method (which is a variation of method 1) to compute allowable stresses. This option should be discussed with the research engineer and the AFED project engineer, and all individuals should agree on the merits of using this method. Method 1A is intended for situations where the allowable stresses of method 1 cannot be met because the stress concentration effects are included in areas where the stress state is well defined (e.g., a model string that contains a small hole and is loaded in bending). In this particular case, the structure will not fail immediately, but there is concern that a localized stress concentration can occur that could lead to a fatigue failure. In such cases, the allowables of method 1 may be used without including the stress concentration effects. However, the stress concentration effects must be used in a fatigue analysis to demonstrate that fatigue failure is not a problem.

4.5.3 Stress computations using method 2.—This method to determine allowable stresses can be used when the model system cannot be designed to the allowable stresses that are defined by methods 1 or 1A. Before a model system can be designed to the allowable stresses defined in this section, the stress state must be understood to a high level of confidence. Closed-form solutions and standard handbook calculations will, in many cases, suffice. However, if the model system takes the form of a highly indeterminate complex structure, a more in-depth analysis will be required using state-of-the-art structural analysis codes that employ finite-element or finite-difference techniques.

The allowable limits for simple and combined stresses are the smaller of two-thirds of the minimum yield stress or one-third of the minimum ultimate stress of the material. This corresponds to a safety factor of 1.5 on yield stress and of 3.0 on ultimate stress.

4.6 Model Stability

The rigid body motion about the principal axes of the model system should be considered to verify the model system stability. In addition, model system flexibility in the pitch, yaw, and roll planes should be considered to verify aeroelastic stability.

4.6.1 Model system stiffness.—Model system stiffness verification is a source of concern when the modeling system is a long, slender, columnar configuration to be tested at an angle of attack under dynamic pressure loading. For this type of test, the expected dynamic total pressure must not exceed one-half the model design dynamic total pressure. The design dynamic total pressure should be based on the angle of attack plus 10°.

4.6.2 Model dynamics.—Models to be dynamically tested must be analyzed to verify that the mountings and/or restraints are structurally adequate and dynamically stable (i.e., as the energy of the model is increased during testing, the energy of the model mountings or restraints do not increase). If a model is to receive specialized dynamic testing (e.g., fan or compressor blade flutter, or compressor rotating stall), the instrumentation requirements and model operation should be addressed in the model stability report mentioned in section 6.1.4.

4.6.3 Model system buckling.—The allowable compressive load in model support columns and in model shroud coverings must not exceed one-third of the Euler critical buckling load for the appropriate end conditions.

4.7 Pressure Systems

4.7.1 Model support pressure systems.—Model, support, and test equipment that uses hydraulic, pneumatic, or any other type of system with operating pressures that exceed 15 psig must be designed, fabricated, inspected, tested, and installed in accordance with the specifications outlined in the ASME Boiler and Pressure Vessel Code, the ANSI codes of the ASME, and the Department of Transportation (DOT) regulations. Pressure vessels are defined as all shells, chambers, tanks, or components that are used to transmit a gas where the pressures exceed 15 psig. The welding of pressure vessels must be in accordance with the ASME Boiler and Pressure Vessel Code.

The research engineer should provide the following information on all components of a pressure system to the AFED project engineer to prevent system capacity violations: system volume, temperature range, working pressure, and the proof test pressure. AFED suggests that all components of a pressure system be stored in a clean, dry, and sealed condition after proof testing and prior to delivery to the facility.

4.7.2 Pressure-relief devices.—Pressure-relief devices may be required in a hydraulic, hydrostatic, or pneumatic system, but not necessarily in the model. If the system is not rated for the pressure emanating from the pressure source, these devices should be capable of relieving the overpressure by discharging sufficient flow from the pressure source under the conditions causing the malfunctions.

4.7.3 Pressure piping systems.—All model and support system piping must be designed, fabricated, inspected, tested, and installed in accordance with information presented in the latest edition of the ANSI/ASME Standard Piping Code. Powered models have internal piping that falls under this code. Pressure vessels that are constructed from standard pipe fittings and standard flanges are also considered pressure piping and use the ANSI/ASME Standard Piping Code.

The welding of pressure piping must follow the procedures that are outlined in the ASME Boiler and Pressure Vessel Code as well as in the ANSI/ASME Standard Piping Code B 31.1 and B 31.3. All service lines

into or out of a model should be labeled with the proper working pressures, flow direction, and fluid or gas being carried.

4.8 Force Balance System

The Icing Research Tunnel is the only Lewis tunnel that maintains a force balance system. When tests are to occur in other tunnels, the research engineer must supply the force balance system if one is needed. The Icing Research Tunnel project engineer can discuss the force balance system with the customer at one of the pretest meetings.

4.9 Rotating Systems

The requirements in this section apply to model systems with rotating parts (such as propeller or fan models) that are to be tested in the 8- by 6-Foot Supersonic Wind Tunnel, the 9- by 15-Foot Low-Speed Wind Tunnel, the 10- by 10-Foot Supersonic Wind Tunnel, or the Icing Research Tunnel facilities. In addition, certain parts of this section apply to turbine engines that might be tested in the 10- by 10-Foot Supersonic Wind Tunnel.

4.9.1 Propeller model design.—Propeller model systems must be designed to withstand the maximum unbalanced load that could occur because of blade loss. The model system should be equipped with a control system that senses an unbalanced load and overspeed, and initiates an automatic shutdown of the rig. Propeller model systems should also be designed to operate at a 20 percent overspeed without model system damage. Provision should be made that the system (i.e., the propeller model and the drive system) is properly balanced.

4.9.2 Rotating model system analysis.—The research engineer should provide the AFED project engineer with propeller model system resonance points if any exist. Before a rotating model or turbine engine can be tested in a Lewis wind tunnel, the customer must provide the AFED project engineer with a Campbell diagram that shows possible resonance points (i.e., intersection points between natural frequency lines and engine order lines). Model system excitation frequencies that result during model tests should differ from model system natural frequencies by at least 10 percent.

4.9.3 Structural testing of rotating components.—If the structural integrity of a fan or compressor rig is to be verified, then one blade from each manufactured set of rotor blades should be tested to 1.25 times the maximum expected centrifugal load. This test can be done either statically or dynamically and should be developed by the model design engineer in concert with the blade manufacturer. The tests can be performed on a test specimen that simulates the section of the blade that is under critical loading.

Frequency response checks must be performed for each blade in a propeller, fan, or compressor rig. Each blade should be clamped in a fixture at the root. These frequency checks must be performed by the blade manufacturer to determine the structural similarity of the blades by comparing the first mode (bending or torsion) frequency. The blade manufacturer should specify the acceptable variation in blade frequency response levels and notify the model design engineer, the research engineer, and the AFED project engineer.

4.9.4 Balancing.—The blade manufacturer should specify the acceptable difference in weight and center-of-gravity between the various blades that comprise a propeller, fan, or compressor rig and should notify the model design engineer, the research engineer, and the AFED project engineer. The assembled system must be statically and dynamically balanced.

4.9.5 Prerun testing of rotating models.—Runup testing of a rotating model system should be demonstrated at the model manufacturer's plant prior to shipping the model to NASA Lewis. The tests must demonstrate safe operation over all operational speed ranges and at up to 20 percent overspeed for propeller test rigs and to 10 percent overspeed for rotor systems (i.e., fan or compressor rigs). A lower overspeed condition may be approved by the research engineer and the AFED project engineer (see definitions, sec. 3.1) if there are aeromechanical stability considerations.

4.9.6 Inspection.—All components of a rotating model system, including the blades, drive shaft, bearings, hub, and other parts, must be thoroughly inspected at the time of manufacture and assembly by the rotating model manufacturer. Inspections of the rotating model may be required at established intervals during testing at NASA Lewis. The required inspection methods should be developed by the rotating model manufacturer with the concurrence of the research engineer and the AFED project engineer.

4.10 Nondestructive Testing of Instrumentation Rakes

If instrumentation rakes are to be placed upstream or inside of propeller rigs, fan or compressor rigs, or turbine engines as part of facility tests; then, the following procedure should be followed to verify instrumentation rake design. It is paramount that instrumentation rake failure does not occur. Severe damage to the model as well as damage to the facility must be averted. The current Lewis procedure calls for the manufacture of one prototype rake for each different rake design that is to be used in conjunction with a propeller, fan or compressor rig, turbine engine, or test article experiment in one of the facility test sections. One build of each different rake design is rigorously tested. This prototype rake is subjected to shock and vibration tests. The remainder of the rakes of similar geometry that are to be used in the turbine engine/test article are subjected to low-level vibration testing. Table III of reference 5 shows the vibration and shock test schedule for the prototype rake (i.e., sinusoidal sweep, dwells, random vibration, and shock test) and the sinusoidal sweep schedule for the flight-type rakes. Fatigue testing for the evaluation of jet-engine probes is discussed in reference 6. The test schedule for the prototype rake and the flight-type rakes should be agreed to by the research engineer, the AFED project engineer, and a member of Lewis' Structural Systems Division (Structural Systems Dynamics Branch).

4.11 Electrical Equipment and Components

The flow environment in the test sections of Lewis facilities requires the use of only qualified hardware, equipment, and material that conforms to the National Electrical Code (NEC). All wires on all pressure transducers, strain gauges, vibration pickups, and other low-voltage devices should be shielded. Design details regarding customer-supplied control panels, the associated wiring to the facility control room, electrical wiring diagrams, and connectors at interfaces located at control boxes or the model exterior should conform to the NEC. These details should be discussed with the AFED project engineer and the AFED electrical engineer at one of the pretest meetings.

4.12 General Periodic In-Service Inspection

All model system components that are critically loaded must be inspected during testing at time intervals that are mutually agreed upon by the research engineer and the AFED project engineer. These inspections may include force balances (that are customer supplied), stings, model lifting surfaces, flaps, fasteners, and other items that must be guarded against fatigue failure. The periodic inspection requirements should be documented and included in the model systems report (sec. 6.1).

5.0 QUALITY ASSURANCE

This section provides the quality assurance criteria for facility model systems that are to be tested at NASA Lewis. These criteria are intended to assure that the as-built model system hardware meets the model design specifications.

5.1 Implementation Responsibilities

Specific quality assurance criteria will be determined in view of model system complexity and criticality with regard to model system failure and/or damage. Each project must have an AFED work plan available at least 1 year before the tunnel test time. The research engineer must meet with the AFED project engineer to discuss the AFED work plan before the AFED project engineer develops this document. The AFED work plan should include such topics as (1) research objectives of the tests, (2) program background information, (3) testing facility, (4) test conditions, model configurations, and test matrix, (5) test hardware required (e.g., schlieren system, special transducers, and instrumentation rakes), (6) support system requirements, (7) data accuracy requirements, (8) data analysis and data reduction requirements, (9) work schedule breakdown, and (10) project task assignments and responsibilities. The following list delineates the people responsible for determining applicable quality assurance requirements for each model system:

- (1) Lewis in-house model systems—The AFED project engineer determines the requirements.
- (2) Contract model systems—The AFED project engineer approves quality assurance requirements and/or standards to be implemented by the contractor.
- (3) User-furnished model systems—Customers must provide their AFED project engineer with documented evidence of their compliance with the intent of this chapter. At the first pretest meeting (usually 1 year in advance of the tunnel test), the AFED project engineer tells the customer what documentation is required. This documentation can be included as part of the model systems report (see sec. 6.1).

5.2 Quality Assurance Criteria

5.2.1 Purchase orders.—Purchase orders for model systems parts and materials must identify appropriate procurement quality assurance requirements. Only NASA- or contractor-approved drawings and specifications are used to purchase parts or materials.

5.2.2 Receiving inspection.—The engineer ordering the hardware must inspect the hardware upon receipt. When requested, this inspection may be performed by a designee of the engineer placing the order. Receiving inspection documentation must include the purchase order number, purchase order item number, contract number (if applicable), supplier name, part number, raw material information, and the inspector's signature.

Evidence of the following supplier inspections and tests, as defined in the purchase documentation, must be verified during the receiving inspection:

- (1) Material certification test document
- (2) Evidence of supplier inspection acceptance
- (3) Certification of heat treatment process
- (4) Certification that the end item is from the material specified
- (5) Test data
- (6) Inspection reports
- (7) Other documentation as specified on the purchase order

After the receiving inspection, supplier data and documentation must be maintained by the ordering engineer and delivered with the hardware.

5.2.3 Model fabrication.—The model design engineer oversees the fabrication of the model (see sec. 3.1).

5.2.3.1 Traceability and control: Raw materials and parts used in the fabrication and assembly of model systems must be controlled to maintain identification and traceability.

5.2.3.2 Controlled storage: Raw materials, parts and fasteners must be stored in a dedicated, controlled-access storage area.

5.2.3.3 Configuration control: The Aeronautics Directorate maintains the end-item hardware configuration by controlling drawing and specification changes. The research engineer and the AFED project engineer assure that obsolete drawings and specifications are withdrawn and destroyed.

Identification: When necessary, model system hardware is identified by electrolytic etch, or other methods, on a surface (see SAE Aerospace Standard 478G) that will not affect flow or structural integrity. The model identification is posted on the model's container.

Drawing and specification control: Drawings and specifications define the complete as-built configuration and provide a record of the design. The model design engineer must provide the research engineer and the AFED project engineer with a copy of all revised drawings for use in the final hardware inspection.

Red-line changes: Red-line changes may be used to change drawings temporarily during the fabrication process. Red-line changes must be approved by the research engineer and the AFED project engineer. These changes are initialed and dated on the face of the fabrication drawings prior to implementation. They are incorporated into the next revision of the drawing.

5.2.3.4 Fabrication planning: The AFED project engineer coordinates the fabrication and inspection effort with Lewis' Fabrication Support Division (for in-house models). Inspection records are maintained as long as deemed necessary by the AFED project engineer.

5.2.4 Nonconforming hardware control.—When a test article (e.g., tunnel test section calibration arrays, cone cylinder assemblies, or boundary layer rakes) does not conform to applicable drawings, specifications, or other requirements, it is identified as nonconforming. The AFED project engineer, after consulting with the other project team members (e.g., the research engineer, the assigned Lewis Structural Systems Division engineer, and the AFED operations engineer), decides if a test article must be reworked. Test article rework is supervised by Lewis' Fabrication Support Division (Fabrication Procurement Office) for outside procurements and by the AFED project engineer for Lewis-manufactured items. All engineering drawings are updated to reflect test article changes. Then, the revised test article must be approved by the safety committee.

5.2.5 Wind tunnel test section calibration control.—According to their policy, AFED periodically calibrates the test sections of the Lewis wind tunnels. For these calibrations, AFED uses cone cylinder assemblies of various sizes (to measure axial static pressure distribution), test section instrumentation rake arrays (to measure static pressure, total pressure, and total temperature distribution at various test section locations), and boundary layer rakes to determine test section sidewall effects. The AFED wind tunnel test section calibration team can address specific problems that customers may have to ensure that model data is of the required accuracy. The customer can obtain reports on tunnel test section calibration results from the appropriate facility manager.

5.2.6 Model and facility equipment calibration control.—The AFED project engineer is responsible for calibrating model pitch, yaw, and roll movement (if required); wind tunnel test section strut height; and mass flow plugs that are used with model nozzle systems. The customer can request that the AFED project engineer provide other model calibrations to ensure that the model data recorded are of the required accuracy.

5.2.7 Metrology control.—The instruments used to measure or verify compliance to drawing and specification requirements must be in current calibration, and evidence of the calibration must be displayed.

5.2.8 Handling, packing, and shipping.—Hardware must be protected from damage during all phases of manufacturing and shipping. The model design engineer or the AFED project engineer will document any special handling, packing, and shipping requirements for model system hardware. Shipping containers are to be designed to ensure safe arrival and ready identification. Containers for finished hardware must identify individual parts and must contain a complete set of as-built drawings, including assembly procedures.

5.3 Records

Quality assurance records are maintained by the AFED project engineer for at least 6 months after testing is complete. AFED suggests that the research engineer also maintain a set of the quality assurance records for the same length of time.

6.0 DOCUMENTATION

6.1 Model Systems Report

A model systems report is required for all model systems that are to be tested at NASA Lewis. The model systems report is to be a complete, comprehensive stand-alone document. The customer must submit the model systems report to the AFED project engineer at least 2 months prior to tunnel entry, but the AFED project engineer may request an earlier delivery date for the report. The AFED project engineer establishes the content of the model systems report from the information outlined in the following sections.

6.1.1 Model system drawings.—The model system drawings include the as-built drawings of the model system configuration to be tested and (where applicable) assembly drawings, installation drawings, electrical sketches, and wiring diagrams.

6.1.2 Model design load calculations.—The design load calculations must take into account model specifications and requirements. Derived loads must consider aerodynamic, mechanical, and thermal effects. Life-cycle requirements must also be addressed.

6.1.3 Model stress report.—The model stress report must summarize all the safety factors that are used in model engineering calculations. General equation sets, terms, and computer programs must be referenced. Any assumptions that are used in equation set development must be properly noted. The model stress report should also specify material data for all components that comprise the model system as well as for fasteners that are used to secure model components together. The material data should include standard properties and adjusted properties (i.e., pressure, temperature, or other environmental effects).

Stress calculations must be supplemented by model section sketches that show the appropriate forces and moments at an adequate number of model system stations (see sec. 4.3.1). Detailed shear and moment diagrams for the model system must be presented along with a stress analysis for a worst-case loads scenario.

A structural joint analysis for the model system components must be performed if applicable. This analysis considers bolted, welded, brazed, and bonded joints. A model system component analysis must also be performed for pressurized systems, hydrostatic systems, and specialized model systems that are subjected to fatigue and thermal effects.

6.1.4 Model stability report.—In cases where the model consists of a fan rig, compressor rig, or turbine engine and the test program is dynamic, a report may be required that addresses such specialized topics as blade flutter and rotating stall dynamics. The customer should discuss this requirement with the facility manager and the AFED project engineer at one of the pretest meetings.

6.1.5 Inspection report.—The customer may be required to supply the AFED project engineer with an inspection report. The AFED project engineer initiates this request and specifies the content of the inspection report. The inspection report may contain material certification information (supplier documentation), fabrication planning information (sec. 5.2.3.4), material or nonconforming hardware control information (sec. 5.2.4), and/or quality assurance information.

6.1.6 Test report.—The AFED project engineer initiates the request for the test report, if required. The test report may include material properties, model load information, static and dynamic balancing, and model runup tests (sec. 4.9.5).

6.1.7 Hazard analysis.—In some test sections, a hazard analysis may have to be developed for the model test. The decision to develop this analysis should be made at the first pretest meeting of the customer, facility manager, and AFED project engineer (at least 1 year before the actual tunnel test time). The AFED project engineer will decide if such an analysis is required and what the hazard report should contain. The hazard report can discuss possible damage to the model and the facility if a model failure occurs due to stress, thermal effects, fatigue, instrumentation malfunction, facility power loss, or some other factor. The report is a joint effort of the AFED project engineer and the customer. It is included as part of the model systems report.

6.2 Assembly, Installation, and Configuration Change Procedures

A model system assembly, installation, and configuration change procedure should be established as early as possible, preferably at the first pretest meeting, which should occur at least 1 year before the tunnel test time. The format for this procedure should be agreed upon by the research engineer and the AFED project engineer by the time the model is delivered to the facility for buildup in the selected tunnel test section. Typical procedures or drawings should contain sequential assembly steps, torque values, alignment criteria, and other information necessary to assemble, install, and check out the model and associated hardware in the test section of the Lewis facility selected to test the model.

7.0 MODEL DELIVERY SCHEDULE

Most of the models tested in the facilities at NASA Lewis are complex; therefore, the model buildup time in the facility model preparation areas and facility test sections varies greatly. AFED suggests that the customer (i.e., the research engineer) discuss with the facility manager the appropriate arrival time for the model and any auxiliary equipment that is customer supplied.

8.0 DEVIATIONS

Customers (i.e., research engineers) who consider it necessary to deviate from the requirements in this manual should submit a written request for approval to the facility manager and the AFED project engineer. Approval or denial of the request will be documented by the AFED project engineer and retained in the AFED facility files.

8.1 Deviation Requests

Deviation requests are submitted by the customer (i.e., research engineer) through the AFED project engineer to the appropriate facility manager. The AFED project engineer with the concurrence of the facility manager provides or obtains an evaluation from the proper Lewis authority for the model/facility deviation request. The facility manager and the AFED project engineer may request the assistance of the AFED Chief, appropriate AFED branch chiefs, the Center's Environmental Compliance Office, members of the appropriate area safety committee, or other Lewis committees or organizational groups as required. A copy of the deviation request should be sent to the chairman of the appropriate area safety committee and the chief of the Office of Mission Safety and Assurance at NASA Lewis.

The customer (i.e., research engineer) drafts the deviation request, which should contain the following information:

- (1) The component or model system under consideration
- (2) The test plan requirement that calls for a deviation in standard operation of the facility or model
- (3) The reason why this test plan requirement cannot be achieved under normal operating procedures
- (4) Technical information supporting the claim that a deviation from normal facility or model system operation is acceptable

8.2 Approval Authority

If a customer model failure could result in minor damage to a Lewis aeropropulsion facility, the facility manager and the AFED project engineer must seek the approval of AFED management before a deviation in test procedures is permitted. The Lewis chief counsel will be notified, and before testing begins, an agreement between the customer and AFED management will be made regarding model and facility liability.

9.0 APPENDIX A

LEWIS CONTACTS

The name of the appropriate facility manager can be obtained from a Lewis Research Center Telephone Directory. This information is presented in the organizational listing under Aeropropulsion Facilities and Experiments Division, Facilities Management Branch (organizational code 2810). The Lewis switchboard operator ((216) 433-4000) can also provide the names of the appropriate facility managers. Mail correspondence can be addressed as follows:

NASA Lewis Research Center
Attn: (Facility Name) Facility Manager
Mail Stop 6-8
21000 Brookpark Road
Cleveland, Ohio 44135

10.0 APPENDIX B

HOW TO OBTAIN TEST TIME IN ONE OF THE WIND TUNNEL FACILITIES UNDER THE DIRECTION OF AFED

- (1) The customer contacts the appropriate AFED facility manager at least 1 year prior to the test (more advance notice is usually required).
- (2) The appropriate AFED facility manager and key facility personnel review the request (at least 1 year prior to the test).
- (3) For non-NASA requestors only, the customer submits a formal letter of request (at least 1 year in advance of the test) to the Director of Aeronautics at NASA Lewis.
- (4) For non-NASA requestors only, if the project is accepted, a test agreement is prepared and signed. The test agreement outlines the legal responsibilities of NASA Lewis and the customers during the time that the project is at NASA Lewis. The customer is required to sign the test agreement and return it to NASA Lewis. The four types of test agreements follow:

- (a) NASA test program
- (b) NASA/industry cooperative program (nonreimbursable Space Act agreement)
- (c) Other U.S. Government agency programs (reimbursable or nonreimbursable interagency agreement)
- (d) Industry proprietary or noncooperative program (reimbursable Space Act agreement)

11.0 APPENDIX C

BOLT LOADING FOR STRUCTURAL JOINT

An example of bolt loading for a nongasketed flat-faced joint follows. If the bolts have a high preload of 90 percent of proof load, and an external load of up to 100 percent of the preload is applied to the bolts, the bolt tension will increase only a small amount, approximately 10 percent (initial joint compressive stress is nearly canceled by the external tensile stress, ref. 7). The exact amount depends on the relative stiffness between the flange or joint and the bolts and the compression area. The bolt or joint is designed for a safety factor of 3.0 to 5.0 (based on the yield or ultimate stress as the controlling factor). On the basis of these safety factors, the actual bolt stresses will be equal to one-third to one-fifth of the allowable stresses. Because bolt stresses and loads are proportional, the bolt loads will vary from 33 to 20 percent of the allowable loads, and the bolt preload will be 90 percent of the proof load. Therefore, if the bolt does not fail during tightening, it will not likely fail under static loads. Cyclic, tensile, and thermal loads would still have to be considered.

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